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POLARIZED PROTON ACCELERATION AT THE BROOKHAVEN AGS - AN UPDATE*

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Abstract

The RHIC spin design goal assumes 2×10^{11} proton/bunch with 70% polarization. As the injector to RHIC, polarized protons have been accelerated at the AGS for years to increase the polarization transmission efficiency. Several novel techniques have been applied in the AGS to overcome the intrinsic and imperfection resonances. The present level of accelerator performance is discussed. Progress on understanding the beam polarization behavior is presented. The outlook and future plan are also discussed.

1 INTRODUCTION

Acceleration of polarized beams to high energy in circular accelerators is difficult due to numerous depolarizing resonances. It is particularly difficult in the medium energy range since the limited available straight sections in the existing synchrotrons make it very hard to install a full Siberian Snake to correct all kinds of depolarizing spin resonances. During acceleration, a depolarizing resonance is crossed whenever the spin precession frequency equals the frequency with which spin-perturbing magnetic fields are encountered. In the presence of the vertical dipole guide field in an accelerator, the spin precesses $G\gamma$ times per orbit revolution [1], where $G = (g-2)/2 = 1.7928$ is the gyromagnetic anomaly of proton, and γ is the Lorentz factor. The number of precessions per revolution is called the spin tune ν_s and is equal to $G\gamma$ in this case.

There are three main types of depolarizing resonances: imperfection resonances, which are driven by magnet misalignments; intrinsic resonances, driven by the vertical betatron motion through quadrupoles; and coupling resonances, caused by the vertical motion with horizontal betatron frequency due to linear coupling [2]. The resonance condition for an imperfection resonance is $\nu_s = n$, where n is an integer. The resonance condition for an intrinsic resonance is $\nu_s = nP \pm \nu_y$, where n is an integer, P is the superperiodicity of the AGS, and ν_y is the vertical betatron tune. The resonance condition for a coupling spin resonance is $\nu_s = n \pm \nu_x$. It is only important in the vicinity of a strong intrinsic resonance. The spin resonance strength ϵ_k is defined as the Fourier amplitude of the spin perturbing field. When a polarized beam is uniformly accelerated through an isolated spin resonance, the final polarization P_f is related to the initial polarization P_i by the Froissart-Stora formula[3]

$$P_f = (2e^{-\pi|\epsilon_k|^2/2\alpha} - 1)P_i, \tag{1}$$

where α is the resonance crossing rate given by $\alpha = \frac{d(G\gamma)}{d\theta}$, and θ is the orbital angle in the synchrotron.

The Brookhaven AGS has been accelerating polarized protons since the 1980s. Over the years, several novel schemes have been developed to overcome these resonances in the AGS. At the AGS, a 5% partial Siberian Snake [4] has been used to overcome the imperfection resonances [5] and an ac dipole has been used to overcome strong intrinsic resonances [6]. For a ring with a partial snake with strength s, the spin tune ν_s is given by

$$\cos \pi\nu_s = \cos\frac{s\pi}{2}\cos G\gamma\pi, \tag{2}$$

where $s = 1$ corresponds to a full snake, which rotates the spin by 180°. When s is small, the spin tune is nearly equal to $G\gamma$ except when $G\gamma$ equals an integer n, where the spin tune ν_s is shifted away from the integer by $\pm s/2$. Thus, the partial snake creates a gap in the spin tune at all integers. Since the spin tune never equals an integer, the imperfection resonance condition is never satisfied. Thus the partial snake can overcome all imperfection resonances, provided that the resonance strengths are much smaller than the spin tune gap created by the partial snake. By adiabatically exciting a vertical coherent betatron oscillation using a single ac dipole magnet, an artificial spin resonance is excited. If the resonance location is chosen near the intrinsic spin resonance, the spin motion will be dominated by the ac dipole resonance, and full spin flip can be achieved. The ac dipole was used to overcome the four strong intrinsic spin resonances in the AGS. It generated a full spin flip without significant emittance growth. The two betatron tunes have to be well separated to reduce the coupling effect.

2 ACCELERATION OF POLARIZED PROTONS

The accelerator complex of the Brookhaven AGS and RHIC is shown schematically in Fig.1. The polarized

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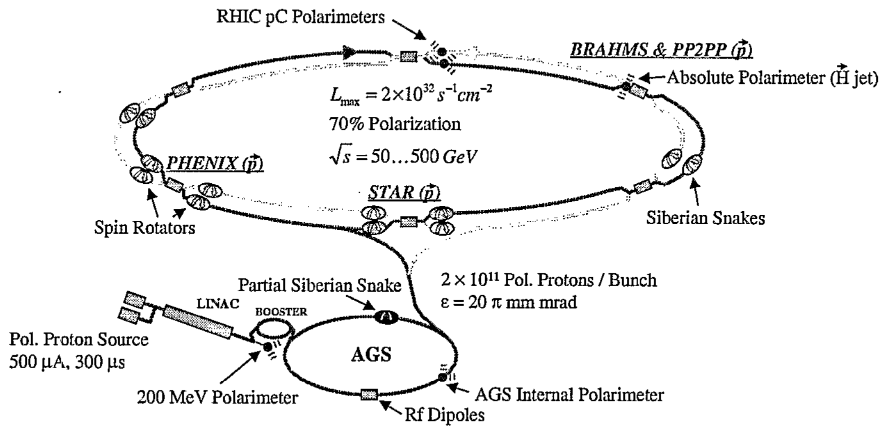

Figure 1: The Brookhaven polarized proton facility complex, which includes the OPPIS source, 200 MeV LINAC, the AGS Booster, the AGS, and RHIC.

H^- beam from the optically pumped polarized ion source (OPPIS) [7] was accelerated through a radio frequency quadrupole and the 200 MeV LINAC. The beam polarization at 200 MeV was measured with elastic scattering from a carbon fiber target. The polarimeter was recently upgraded to accommodate the much higher beam intensity delivered from the new source, and absolute calibration runs with a p+Deuteron [8] polarimeter were also conducted during this running period. The polarization measured by the 200 MeV polarimeter was about 70% over the whole run. The beam was then strip-injected and accelerated in the AGS Booster up to 1.5 GeV or $G\gamma = 4.7$. Only one bunch of the twelve rf buckets in the AGS was filled and the beam intensity varied between 1.3 -1.7×10^{11} protons per bunch. The polarized proton beam was accelerated up to $G\gamma = 46.5$ or 24.3 GeV kinetic energy. Normally the acceleration rate is $\alpha = 4.8 \times 10^{-5}$. The acceleration rate was much slower in last run, $\alpha = 2.4 \times 10^{-5}$, due to the fact that a back-up AGS main magnet power supply had to be used. To compensate for the slow acceleration, the partial snake strength was reduced to 3% in the low energy part: the partial snake was 3% before $G\gamma = 21$, and ramping up to 5% afterwards. This function optimized the beam polarization measured at AGS extraction. The beam polarization at AGS extraction was only $\sim$ 30% due to this slow ramp rate which enhanced the effect of depolarizing resonances. The coupling effect was also studied extensively at $G\gamma = 0+\nu_x$ and is reported in [10]. The AGS polarization performance is summarized in Fig. 2.

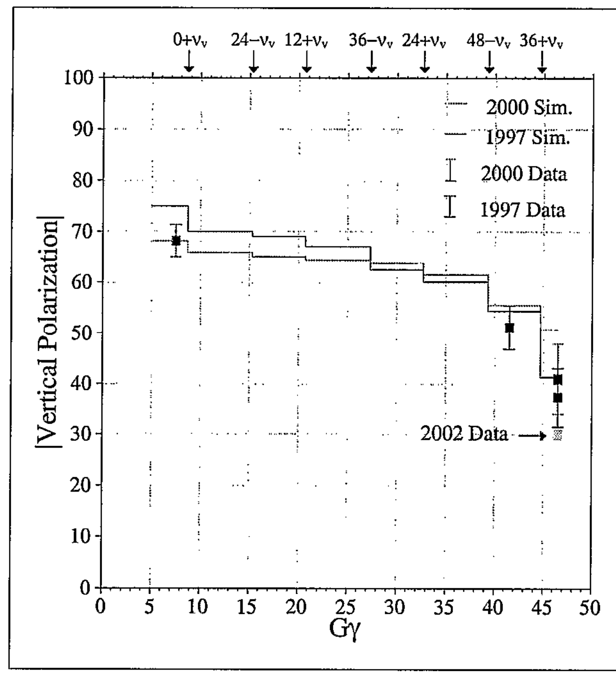

Figure 2: Summary of beam polarization in the AGS. The two solid lines are the simulation results for different beam conditions in year 1997 and 2000, respectively.

As can be seen from Eq.(2), with a strong enough partial snake, the spin tune gap can be increased to allow placing the betatron tune inside the gap so the intrinsic resonance conditions can also be avoided. Simulations showed that for the strongest resonance at $G\gamma = 36 + \nu_y$, a 20% partial snake is needed while $G\gamma = 0 + \nu_y$ can be corrected with a 10% partial snake. Most recently, a 10% partial Siberian Snake was used to successfully accelerate polarized proton passing $0 + \nu_y$ depolarizing resonance in the AGS. The critical element of this operation is to maintain beam stability with the betatron tune close to an integer. No noticeable depolarization was observed due to $0 + \nu_y$. This opens the possibility to use a 20% to 30% partial Siberian Snake in the AGS to overcome all weak and strong intrinsic resonances with one device in the future. For the AGS, this method has several advantages. First, it works for both strong and weak intrinsic resonances. Currently, there is no effective way to overcome the weak intrinsic resonances in the AGS. Second, if coupling of the newly designed snake can be reduced, the strength of coupling resonances can also be reduced. Or, if both horizontal and vertical tunes can be put into the spin tune gap, both intrinsic and coupling resonances can be avoided.

3 POLARIMETER ISSUES

A relative polarimeter was used to monitor the beam polarization in the AGS for many years. It has been operated at beam momenta from 3- 24 GeV/c, or slightly above injection energy to the extraction energy. In the past, the polarization in the AGS was measured with both carbon and nylon targets. The carbon target was capable of withstanding reasonably high beam intensities, up to 1.8×10^{11} at extraction energy. Absolute calibrations have been performed by comparing the asymmetries from both targets to subtract background from the nylon target. This technique does not work at low energy since the beam size is large and can hit both targets. To get a more precise understanding of the background, two forward arms were installed. The recoil and forward arms coincidence was used to choose *pp* elastic events. In addition, the two targets were separated more to make sure there is no contamination. With the newly installed forward arms, the polarization was measured at $G\gamma = 7.5$. Polarization was measured several times during the run at $G\gamma = 7.5$ and the results were compared with polarization measured at the end of 200 MeV LINAC as shown in Fig. 3. It shows that the polarization from the source varies from time to time but the measurements from the end of LINAC and AGS injection agreed very well.

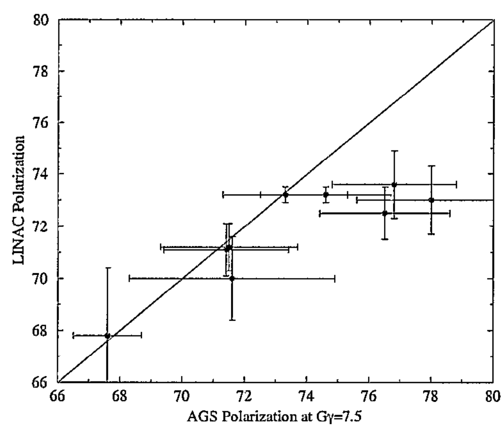

Figure 3: Comparison of polarization measured at the 200 MeV polarimeter and the AGS polarimeter(at $G\gamma = 7.5$). The diagonal line is plotted for a ratio of one. The average polarization from the data are as follows: 72.1±0.6 for AGS; 72.6±0.2 for 200 MeV. The ratio is consistent with one.

Similarly, the polarization was also measured at AGS extraction and RHIC injection for each RHIC fill. The spin transmission efficiency of AGS to RHIC transfer line is 96% at $G\gamma = 46.5$. The ratio of polarization measured at the AGS polarimeter(at $G\gamma = 46.5$) and the RHIC injection is close to one [9].

The scintillator counters of the current internal polarimeter will be saturated if the event rate is too high. To run the polarimeter with the intensity of 2×10^{11} generated from the new source, the target thickness must be reduced. A typical polarization measurement at RHIC injection energy takes about 30 minutes to reach a statistical error of ±4%. The AGS polarization tuning can be greatly improved with a fast and reliable polarimeter. Actually, the p-Carbon CNI polarimeter is a good candidate [9].

The CNI polarimeter equipped with silicon strip detectors in both RHIC rings and the fast electronics system based on the waveform digitizer module enabled us to measure the asymmetry with enough statistics within one minute in RHIC. It is estimated that if six bunches are injected into AGS, with a carbon ribbon target wider by a factor of 100, the polarization measurement at RHIC injection energy can be done in one minute for the same statistical error ±4%. The new polarimeter is under construction and will be installed at the end of summer.

4 FUTURE PLAN

The polarization loss in the AGS is dominated by the losses at the weak intrinsic spin resonances and coupling resonances associated with the strong intrinsic spin resonances. The OPPIS source intensity has exceeded requirement for RHIC and polarization reached 75-80% in a recent test. The source polarization needs to be above 80% for 70% at RHIC. With the higher polarization from the source and the main magnet power supply back on line, the goal for next run is to reach 50% polarization in RHIC. The new CNI polarimeter in the AGS will greatly improve polarization tuning efficiency. With the new AGS partial snake installed, 70% polarization should be achieved in RHIC.

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